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MAJOR AND MINOR CONSTITUENTS OF ALUMINUM ALLOYS

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An accurate analysis of aluminum alloys is required for quality control and characterization purposes. The two analytical techniques, atomic absorption spectroscopy and inductively coupled plasma atomic emission spectroscopy are used for the determination of major (Mg, Li, Cu, Zn, Ti, Si) and minor and trace (Be, Zr, Fe, Pb, Co, Ni, Cr, Mn, etc.) constituents of various aluminum alloys. Results obtained by the ICP-AES method are similar to that obtained by the AAS method for most of the elements. It was found that analysis for Be, Zr, Ti and Si was more efficient and sensitive by the ICP-AES method, whereas poor reproducibility was obtained for lithium. This method allowed the determination of major and minor constituents in the same solution without dilution. Comparative data is presented for standards and sample alloys obtained by both techniques. (Keywords)

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INTRODUCTION

The introduction of advanced materials has resulted in the development of light weight, high strength, thermal and corrosion resistant structures for aerospace applications. These materials allow the flexibility required in designing the engine and airframe of an aircraft. To achieve the enhanced metallurgical properties of a desired product, major constituents of an alloy play an important role. Addition of certain constituents such as lithium, copper, etc. to aluminum alloys has been shown to alter strength, corrosion resistance, etc. Therefore, it becomes necessary to monitor the finished product for its constituents and contaminants which may compromise the quality of the product. Several analytical techniques have to be used to obtain the necessary data from the analyses of these alloys.

In industries, the most common methods of chemical analysis of aluminum alloys are direct reading emission spectographic, gravimetric and photometric methods. These methods are time consuming to perform a complete elemental analysis of the alloys. Atomic absorption spectroscopy (AAS)[1-5] is a well established analytical method to determine major and trace constituents in an alloy. Inductively coupled plasma-atomic emission spectroscopy (ICP-AES)[6,7] is a multielement technique where the analysis is free of chemical interferences and has a large working linear range. Effects of instrumental parameters[8], sample uptake[9-10], interelement interferences[11-14], matrix matching [14-16], and effects of acid types and concentrations [17-20] have been studied for various types of alloy analyses. In this report analytical data for the comparative analyses of aluminum alloys by AAS and ICP-AES methods is presented. These two methods were used to identify a machine part, alloy typing and composition analysis of the starting and the finished product. Aluminum alloys studied were standard reference cast alloy materials fromNational Bureau of Standards, Al-Mg-Li, Al-Mg-Cu, Al-Sn, Al-Zn, and Al-Ti.

EXPERIMENTAL PROCEDURES

INSTRUMENTATION

Atomic absorption spectrophotometer, Perkin Elmer Model 3030
Single element hollow cathode lamps, Perkin Elmer & Fisher Sci. Co.
Inductively coupled plasma-atomic emission spectrophotometer, Perkin Elmer Model ICP/6000 equipped with Model 7500 Computer

MATERIALS AND REAGENTS

Aluminum alloys from National Bureau of Standars, Highes, Valimet and Alfa Products
Standard solutions for 19 elements from SPEX Industries
Hydrochloric, hydrofluoric, nitric and sulfuric acids, Baker Analyzed Reagent Grade
Teflon beakers and Nalgene plastic ware for hydrofluoric acid dissolution of samples for high silicon content analysis

GASES

Acetylene, Argon, Nitrus Oxide — High purity from Matheson Gas Co.
Air purified,[in-house compressed air]

PREPARATION OF STANDARD SOLUTIONS

Standard solutions were prepared by serial dilution of the stock solutions with deionized distilled water. Acid concentrations of each standard solution was maintained at 1-2 percent depending on the acid present in the sample solutions.

PREPARATION OF SAMPLE SOLUTIONS

Chips and drillings from the standard reference materials and other aluminum alloys received for chemical analysis were dissolved by one of the following described methods.

METHOD 1

A 0.2 - 0.5g sample (Pure aluminum) was weighed in a beaker and dissolved in 16mL of 25% hydrochloric acid[6]. The beaker was slightly heated on a hot plate for complete dissolution. The solution was transferred to a 100mL volumetric flask to make a known volume with deionized distilled water.

METHOD 2

A 0.2 - 0.5g sample (AL-Mg-Li, Al-Mg-Zn-Cu alloys etc.) was weighed and placed in a beaker. A mixture of 10mL hydrochloric and 2mL nitric acids was added to the sample. The beaker was then heated gently for complete dissolution and the volume was decreased to 5mL. The solution was transferred to a 100mL volumetric flask to make a known volume.

METHOD 3

A 0.2 - 0.5g sample (Al-Ti) was weighed in a teflon crucible of Parr bomb and a mixture of 10mL hydrochloric and 5mL sulfuric acids was added to it. The bomb was heated at 150°C for 24 hours for complete dissolution. The resulting solution was diluted to a 100mL in a volumetric flask with deionized distilled water.

METHOD 4

A 0.2g sample (Al-Sn, Al-Ti) ws weighed in a platinum crucible and fused with 1g sodium carbonate. The resulting melt was dissolved in water and transferred to a 100mL volumetric flask to make a known volume.

METHOD 5

A 0.5g sample (high silicon containing alloy) was weighed and placed in a teflon beaker. A mixture of 10mL water + 8mL hydrochloric acid was added and when reaction subsided 15mL of hydrogen peroxide (50%) was added. The beaker was then heated at 70°C on a water bath for complete reaction, cooled at room temperature and 4mL hydrofluoric acid was added for complete dissolution. The solution was transferred to a 100mL polyethylene volumetric flask and diluted to make a known volume with deionized distilled water.

A qualitative analysis was performed on a Jarrell Ash Emission Spectrograph to identify the presence of jamor and minor constituents of some aluminum alloys. The quantitative analysis of all the aluminum alloys was performed on the atomic absorption spectrophotometer for aluminum, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, nickel, silicon, tin, titanium, tungsten, zinc and zirconium quantities. The experimental parameters used are described in Tables 2 and 3. The hollow cathode lamp current for

arsenic and tin was not stable and the absorbance and concentration values obtained for these two elements were very fluctuating. An average of 3 - 4 readings was taken for each analysis. Calibration graphs were prepared by plotting concentration values of standard arsenic and tin solutions versus their obsorbance values. The concentration of arsenic and tin was then read from the standard calibration curves.

The ICP-AES spectrograph was set up according to the established instrument conditions, Table 4. The experimetnal parametrs used for all the elements analyzed are given in Table 5. An average of three readings was taken for each analysis.

RESULTS

The certified standard reference materials obtained from the National Bureau of Standards and other sources were analyzed for their major, minor and trace constituents by the AAS and ICP-AES methods. Data obtained by these two methods was within the specified limits for each elements present in the alloy. These standards and their set experimental parameters were used to identify an unknown sample and verify its composition. The concentration values for all the elements determined in the standards and the samples were calculated in weight percent. Each value is an average of 3 - 4 readings. Results for most of the alloys analyzed by the two methods were found to be in close corraboration to the standard reference materials, as can be seen from the data presented in Tables 6 thru 13.

Table 6 reports the analysis results fro aluminum cast alloys by the AAS and ICP-AES methods. The values obtained are in good agreement with the certified values. An unknown sample was analyzed for alloy typing purposes. Data obtained for Be, Si, Fe, Mn, Zn, Mg, Cu, Ti, Ni, Pb and Cr were compared with the data from SAC330G, SAC325E, SA338B, SS53 and A357 standard alloy analyses. The sample was identified as A357 type aluminum alloy.

SA338B and A357 aluminum alloys contain high silica content. Hydrofluoric acid digested solution was used for silicon determination. It is a known fact that sodium suppresses ionization of silicon in the hot nitrous oxide flame (3000°C)[4,5]. Since sodium silicqte is used to prepare the standard silicon solution, it was necessary to add sodium equivalent of the standard solution to the sample solutions. Therefore, 5mL of 1000mg/L sodium solution was added to each sample solution prior to silicon determination by the AAS method. It was found that the addition of sodium was not necessary when sodium carbonate fusion method was used for sample digestion.

Results for aluminum-magnesium-lithium and other aluminum-magnesium alloys are presented in Tables 7 thru 9. Determination of lithium in these alloys (Tables 7 and 8) was very difficult by the ICP-AES method. There was a long wait to obtain a reproducible emission response. Data in Table 1 also indicates that the ICP-AES method is not bery sensitive for the lithium determination when compared to the AAS sensitivity.

Some aluminum alloys containing high tin (Table 10) and high zinc (Table 11) content were also analyzed by these two methods. Again, the results obtained are in good agreement with the certified standard values.

Analysis of high temperature aluminum-titanium alloys was a challenge. The starting material (Aluminum powder) used to prepare Al-Ti was analyzed for its impurities. The complete analysis indicted the presence of Si, Cu, Fe and Ni as contaminants. These impurities were carried thru in the manufactured Al-Ti alloys, Table 12. Some elements are present in a larger concentration than in the starting material. Magnesium is absent in the aluminum powder analysis, but is present in the samples # 15 thru 22. It is possible that some of the higher contaminant values could be contributed by the titanium used as the starting materials for these alloys. Titanium could not be obtained for impurity analyses. Samples 15, 17 and 212 were identified to contain

4% titanium, samples 16, 1[illegible] and 22 contain 6% titanium and samples 19 and 20 over 40% titanium. These values were as expected from the manufactured products.

The ICP-AES analyses were performed on aluminum-titanium alloy samples # 15 thru 22 in concentrated solutions as well as in 10 and 100 times diluted solutions. There is not much difference in the values obtained from these three different dilutions of the Al-Ti alloy sample solutions. Results are reported in Table 13.

CONCLUSIONS

The ICP-AES method has been successfully used to determine major constituents of various aluminum alloys. This method is fast and complete analyses for all the possible elements present in the alloy as its consituents or contaminants can be obtained without sample dilution. Accuracy and reproducibility of this technique is close to the well recognized atomic absorption spectroscopic method.

RECOMMENDATIONS

It is recommended that the ICP-AES method should be used for the quantitative analyses of aluminum alloys. This method has been found to be fast and equally sensitive and reproducible when compared to the AAS analyses.

The present studies indicate 2 - 5% higher values for aluminum when present in 70% or higher concentrations in the alloys. A fast deposit on the injection tube (Ceramic) also slows down the analysis.

ACKNOWLEDGEMENTS

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TABLE 1
Selected Wavelengths and Detection Limits for AAS and ICP-AES

Elements	Wavelength, nm		Detection limit, mg/L	
	AAS	ICP-AES	AAS	ICP-AES
Aluminum	309.3	309.271	0.03	0.023
Arsenic	193.7	193.696	0.1	0.053
Beryllium	234.9	313.042	0.002	0.00027
Calcium	240.7	238.892	0.002	0.00019
Cobalt	240.7	238.892	0.01	0.006
Chromium	357.9	205.552	0.005	0.0061
Copper	324.7	324.75	0.002	0.0054
Iron	248.3	238.20	0.004	0.005
Lead	217.0	220.35	0.03	0.042
Lithium	670.85	460.286	0.008	0.857
Magnesium	285.2	279.07	0.0003	0.001
Manganese	279.5	257.61	0.05	0.002
Nickel	232.0	221.647	0.008	0.010
Silicon	251.6	251.60	0.06	0.08
Tin	286.3	189.989	0.03	0.096
Titanium	364.3	334.941	0.05	0.0038
Tungsten	255.1	207.911	1.0	0.030
Zinc	213.9	213.856	0.002	0.0018
Zirconium	360.1	343.823	0.4	0.0071

TABLE 2
Instrumental Parameters for Atomic Absorption Analysis

Elements	Wavelength, nm	Slit, nm	Flame	Sensitivity, mg/L	Optimum range, mg/L
Aluminum	309.3	0.7	N_2O/C_2H_2	1.0	100.0
Arsenic	193.7	0.7	Air/C_2H_2	1.0	100.0
Beryllium	234.9	0.7	N_2O/C_2H_2	0.01	1.0
Calcium	422.7	0.7	Air/C_2H_2	0.01	5.0
Chromium	357.9	0.7	N_2O/C_2H_2	0.06	5.0
Cobalt	240.7	0.2	Air/C_2H_2	0.05	5.0
Iron	248.3	0.2	Air/C_2H_2	0.07	5.0
Lead	217.0	0.7	Air/C_2H_2	0.20	20.0
Lithium	670.8	0.7	Air/C_2H_2	0.03	2.0
Magnesium	285.2	0.7	Air/C_2H_2	0.005	0.5
Manganese	279.5	0.2	Air/C_2H_2	0.04	3.0
Nickel	232.0	0.2	Air/C_2H_2	0.10	7.0
Silicon	251.6	0.2	Air/C_2H_2	1.40	150.0
Tin	286.3	0.7	N_2O/C_2H_2	1.20	100.0
Titanium	364.3	0.2	N_2O/C_2H_2	1.0	200.0
Tungsten	255.1	0.2	N_2O/C_2H_2	7.5	500.0
Zinc	213.9	0.7	Air/C_2H_2	0.01	1.0
Zirconium	360.1	0.2	N_2O/C_2H_2	8.0	800.0

TABLE 3
Selected Parameters for Atomic Absorption Analysis

Element	Lamp current mA	Burner height, mm	Fuel/Oxidant ratio	Characteristic concentration	Calculated Charac. Conc.	Absorbance
Aluminum	30	8.0	30/36	1.100	0.9786	0.430
Arsenic	18	8.2	21/44	1.000	1.107	0.202
Beryllium	25	8.5	21/42	0.025	0.029	0.238
Calcium	25	7.9	20/46	0.092	0.088	0.257
Cobalt	30	8.8	18/45	0.120	0.118	0.229
Chromium	30	9.5	25/40	0.078	0.08	0.276
Copper	20	9.5	21/44	0.077	0.082	0.260
Iron	18	9.5	20/40	0.10	0.105	0.212
Lead	10	8.6	20/40	0.19	0.195	0.440
Lithium	25	10.0	18/40	0.035	0.032	0.400
Magnesium	20	9.5	20/46	0.0078	0.0068	0.315
Manganese	15	8.0	24/47	0.052	0.046	0.201
Nickel	35	9.2	21/42	0.140	0.1347	0.226
Silicon	40	8.0	32/36	2.100	2.2	0.287
Tin	15	7.8	30/38	3.200	3.426	0.199
Titanium	40	8.0	30/36	1.800	1.814	0.224
Tungsten	40	9.0	21/44	9.600	9.752	0.231
Zinc	25	8.2	21/40	0.018	0.0185	0.234
Zirconium	40	9.0	21/44	7.000	7.24	0.222

TABLE 4
Instrument Set-Up Conditions for ICP-AES

RF generator	27.12 MHz
Power	1.25 kW
Reflectance	<5 W
Incidence	1250 W
Plasma flow	12L/min.
Nubulizer flow	0.5L/min.
Nubulizer pressure	20-25psi
Auxillary flow	0.1L/min.
Plasma view height	15mm
Argon gas	high purity

TABLE 5
Experimental Parameters for ICP-AES

Element	Wavelength, nm	Concentration, mg/L*	Estimated Detection limit, mg/L	Sensitivity, mg/L
Aluminum	306.271	10.0	0.023	0.77
Arsenic	193.696	100.0	0.053	1.79
Beryllium	313.042	1.0	0.00027	0.01
Calcium	399.366	0.5	0.00019	0.01
Chromium	205.552	10.0	0.00061	0.2
Cobalt	238.892	10.0	0.006	0.2
Copper	324.754	10.0	0.0054	0.18
Iron	238.204	10.0	0.0046	0.15
Lead	220.353	100.0	0.042	1.43
Lithium	460.286	100.0	0.857	28.57
Magnesium	279.553	1.0	0.00015	0.01
Manganese	257.610	10.0	0.0014	0.05
Nickel	221.647	10.0	0.010	0.34
Silicon	251.611	100.0	0.012	0.40
Tin	189.989	100.0	0.096	0.83
Titanium	334.941	10.0	0.0038	0.13
Tungsten	207.911	100.0	0.0071	1.0
Zinc	213.856	10.0	0.0018	0.06
Zirconium	343.823	10.0	0.0071	0.24

*Concentration of the single element analyte solution used for the wavelength scans from which the prominent lines were determined. From Vassel etc., At. Spectrosc.

TABLE 6
Comparative Analyses of Aluminum Cast Alloys

Element/ Method used	SAC 330G weight %	SAC 325E weight %	SA 338B weight %	SS53 weight %	A 357 weight %	Unknown weight %
Beryllium						
Certified value	NV	NV	NV	NV	0.04-0.07	
AAS	ND	ND	ND	ND	0.040	0.040
ICP-AES	ND	ND	ND	ND	0.040	0.040
Silicon						
Certified value	1.54	5.58	7.31	0.70	6.5-7.5	
AAS	0.97	7.13	7.23	0.32	7.19	6.72
ICP-AES	0.96	6.93	6.93	0.32	7.24	6.68
Iron						
Certified value	0.85	0.44	0.55	0.26	0.2 max.	
AAS	0.846	0.44	0.47	0.25	0.03	0.031
ICP-AES	0.85	0.45	0.52	0.25	0.06	0.031
Manganese						
Certified value	0.18	0.06	0.07	0.02	0.1 max	
AAS	0.17	0.05	0.067	0.01	0.06	0.057
ICP-AES	0.21	0.055	0.065	0.018	0.05	0.06
Zinc						
Certified value	0.15	NV	NV	NV	0.10	
AAS	0.149	0.005	0.005	0.015	0.007	0.007
ICP-AES	0.151	0.004	0.005	0.013	0.007	0.007
Magnesium						
Certified value	0.03	0.66	0.34	1.24	0.4-0.7	
AAS	0.008	0.63	0.30	1.19	0.44	0.447
ICP-AES	0.006	0.60	0.30	1.25	0.45	0.45
Copper						
Certified value	3.32	1.54	0.10	0.04	0.2 max.	
AAS	3.22	1.61	0.10	0.036	0.051	0.051
ICP-AES	3.25	1.57	0.10	0.042	0.054	0.050
Titanium						
Certified value	0.14	0.19	0.20	0.03	0.1-0.2	
AAS	0.12	0.16	0.19	0.022	0.14	0.14
ICP-AES	0.12	0.158	0.191	0.022	0.138	0.135
Nickel						
Certified value	0.06	NV	NV	NV	NV	
AAS	0.057	0.04	ND	0.036	0.101	0.101
ICP-AES	0.051	0.04	ND	0.029	0.101	0.102
Lead						
Certified value	0.06	NV	NV	0.05 max.	0.05 max.	
AAS	0.03	0.005	0.005	0.005	0.009	0.009
ICP-AES	0.05	0.005	0.005	0.004	0.010	0.008
Chromium						
Certified value	NV	NV	NV	0.05 max.	0.05 max.	
AAS	0.008	0.05	0.08	0.286	0.099	0.099
ICP-AES	0.007	0.046	0.072	0.195	0.130	0.085
Aluminum						
Certified value	Balance	Balance	Balance	Balance	Balance	Balance
AAS	93.62	90.21	91.48	97.98	91.91	91.85
ICP-AES	93.71	90.10	91.45	97.86	91.90	91.90

NV = no value given
ND = not detected by the method

TABLE 7
Comparative ANalyses of Al-Mg-Li-Allloys

Sample Number/ Method used	Magnesium, weight %	Lithium weight %	Zirconium, weight %	Silicon, weight %	Iron, weight %	Aluminum, weight %
Standard values	8-10	0.5-2	0.15	0.02	0.01	Balance
S1/AAS	8.22	0.46	0.11	0.005	0.010	91.22
S1/ICP-AES	8.22	0.45	0.13	0.004	0.008	91.41
S2/AAS	8.15	0.456	0.12	0.006	0.010	92.28
S2/ICP-AES	8.19	0.45	0.12	0.006	0.008	91.30
S3/AAS	9.02	1.98	0.11	0.008	0.010	88.89
S3/ICP-AES	9.09	1.98	0.11	0.007	0.008	88.83
S4/AAS	9.45	1.99	0.10	0.007	0.010	88.47
S4/ICP-AES	9.45	2.00	0.11	0.007	0.008	88.43

TABLE 8
Comparative Analyses of Al-Mg-Li-Cu Alloys

Sample No./ Method used	Magnesium, weight %	Lithium weight %	Copper weight %	Zirconium, weight %	Iron, weight %	Silicon, weight %	Aluminum, weight %
Standard value	3	22	1-2	0.120	0.01	0.02	Balance
S5/AAS	2.41	1.57	1.52	0.099	0.011	0.008	93.66
S5/ICP-AES	2.53	1.65	1.50	0.10	0.010	0.007	94.25
S6/AAS	2.56	1.57	1.55	0.11	0.012	0.006	94.23
S6/ICP-AES	2.62	1.65	1.51	0.11	0.010	0.005	94.16
S7/AAS	2.48	2.31	1.44	0.11	0.011	0.005	93.70
S7/ICP-AES	2.47	2.26	1.45	0.11	0.010	0.005	93.71
S8/AAS	2.60	2.12	1.19	0.109	0.012	0.005	94.04
S8/ICP-AES	2.65	2.20	1.25	0.11	0.010	0.005	93.77

TABLE 9
Comparative Analyses of Al-Zn-Mg-Cu Alloys

Sample No. Method used	Zinc. weight %	Magnesium. weight %	Copper. weight %	Iron. weight %	Chromium. weight %	Silicon. weight %	Titanium. weight %	Manganese. weight %	Aluminum. weight %
Standard values	5.86	2.60	1.57	0.25	0.21	0.10	0.04	0.03	89.30
S9/AAS	5.79	2.58	1.55	0.24	0.20	0.10	0.04	0.03	89.53
S9/ICP-AES	5.81	2.55	1.55	0.25	0.20	0.10	0.035	0.028	89.50
S10/AAS	5.82	2.59	1.55	0.25	0.20	0.10	0.038	0.03	89.52
S10/ICP-AES	2.80	2.58	1.56	0.246	0.20	0.10	0.036	0.03	89.45

TABLE 10
Comparative Analyses of Aluminum Alloys Containing Tin

Sample/ Method	Tin. weight %	Zinc. weight %	Silicon. weight %	Copper. weight %	Iron. weight %	Magnesium. weight %	Manganese. weight %	Nickel. weight %	Titanium. weight %	Aluminum. weight %
Standard values	6.3	0.05	0.5-2.0	1.0-2.0	0.35-0.45	0.03-0.84	0.05	0.5-1.2	0.04-1.2	Balance
S11/AA	5.93	0.045	0.184	1.795	0.377	0.121	0.042	0.429	0.062	91.12
S11/ICP-AES	5.89	0.044	0.176	1.785	0.367	0.120	0.048	0.45	0.060	91.01
S12/AA	5.39	0.04	0.123	1.785	0.340	0.021	0.047	0.431	0.058	91.79
S12/ICP-AES	5.43	0.04	0.120	1.775	0.340	0.021	0.045	0.426	0.060	91.75

TABLE 11
Comparative Analyses of Aluminum Alloys Containing Zinc

Sample No./ Method used	Zinc, weight %	Silicon, weight %	Copper, weight %	Iron, weight %	Magnesium, weight %	Beryllium, weight %	Cobalt, weight %	Aluminum, weight %
Standard values	6.5	0.06	1.5	0.06	2.5	0.001	0.40	Balance
S/13 AAS	5.80	0.05	1.072	0.035	2.22	ND	0.31	90.50
S13/ICP-AES	6.39	0.05	1.072	0.035	2.22	0.001	0.30	90.12
S/14 AAS	6.40	0.045	1.08	0.038	2.21	ND	0.31	90.10
S14/ICP-AES	6.35	0.044	1.15	0.04	2.18	0.001	0.31	90.15

ND = not detected by the method

TABLE 12
Comparative Analyses of Aluminum-Titanium Alloys

Sample No./ Method used	Titanium, weight %	Silicon, weight %	Copper, weight %	Magnesium, weight %	Iron, weight %	Nickel, weight %	aluminum, weight %
S15/AAS	3.70	0.099	0.011	0.001	0.031	0.008	96.16
S15/ICP-AES	3.70	0.108	0.010	0.001	0.030	0.005	96.18
S16/AAS	6.04	0.052	0.010	0.001	0.037	0.007	93.87
S16/ICP-AES	6.08	0.061	0.010	0.001	0.034	0.005	93.82
S17/AAS	4.08	0.059	0.054	0.004	0.024	0.007	95.81
S17/ICP-AES	4.25	0.062	0.053	0.003	0.03	0.007	95.70
S18/AAS	6.23	0.069	0.023	0.001	0.03	0.008	93.68
S18/ICP-AES	5.99	0.056	0.021	0.001	0.03	0.009	93.72
S19/AAS	43.15	0.095	0.010	0.019	0.055	0.020	56.92
S19/ICP-AES	43.11	0.088	0.013	0.015	0.057	0.015	56.69
S20/AAS	43.02	0.085	0.010	0.005	0.043	0.014	56.92
S20/ICP-AES	430.6	0.083	0.012	0.005	0.040	0.012	56.79
S21/AAS	4.20	0.030	0.050	0.004	0.019	0.010	95.84
S21/ICP-AES	4.18	0.031	0.044	0.003	0.020	0.010	95.80
S22/AAS	6.07	0.039	0.019	0.001	0.030	0.003	93.89
S22/ICP-AES	6.05	0.040	0.020	0.001	0.040	0.003	93.93
Al powder/ AA	0.00	0.040	0.006	0.000	0.101	0.008	99.84
Al powder/ ICP-AES	0.00	0.039	0.006	0.000	0.090	0.008	99.87

TABLE 13
Analyses of Aluminum-Titanium Alloys by ICP-AES

Sample ID	Titanium, weight %	Silicon, weight %	Copper, weight %	Magnesium, weight %	Iron, weight %	Nickel, weight %
S15 diluted	3.72	0.112	0.012	0.001	0.024	0.005
S15 undiluted	3.686	0.104	0.009	0.001	0.036	0.005
S15 average	3.70	0.108	0.010	0.001	0.03	0.005
S16 diluted	5.966	0.063	0.010	0.001	0.052	0.005
S16 undiluted	6.104	0.060	0.011	0.002	0.017	0.005
S16 average	6.08	0.061	0.010	0.001	0.034	0.005
S17 diluted	4.40	0.064	0.058	0.002	0.024	0.008
S17 undiluted	4.15	0.079	0.047	0.004	0.035	0.007
S17 average	4.25	0.072	0.053	0.003	0.03	0.007
S18 diluted	5.98	0.083	0.072	0.001	0.030	0.004
S18 undiluted	5.99	0.03	0.033	0.000	0.031	0.004
S18 average	5.99	0.056	0.056	0.001	0.03	0.004
S19 diluted	43.14	0.078	0.013	0.019	0.063	0.014
S19 undiluted	43.08	0.078	0.012	0.012	0.053	0.015
S19 average	43.11	0.078	0.013	0.015	0.057	0.015
S20 diluted	43.02	0.150	0.013	0.010	0.037	0.014
S20 undiluted	43.11	0.016	0.014	0.011	0.044	0.010
S20 average	43.06	0.083	0.013	0.01	0.040	0.012
S21 diluted	4.22	0.34	0.047	0.003	0.020	0.015
S21 undiluted	4.15	0.27	0.037	0.004	0.021	0.016
S21 average	4.18	0.31	0.044	0.003	0.020	0.016
S22 diluted	6.04	0.05	0.018	0.002	0.049	0.002
S22 undiluted	6.07	0.03	0.022	0.001	0.040	0.002
S22 average	6.05	0.04	0.020	0.001	0.045	0.002